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## THE INFLUENCE OF BASIC PARAMETERS IN THE WORKING PROCESS OF GAS TURBINE COMBUSTION CHAMBERS

N. N. Kurochkin

In designing combustion chambers for gas turbine plants the parameters are either assumed or are determined by calculation dependent upon preaccepted parameters. All these parameters are closely interrelated so that the value of each parameter affects the values of the others.

Knowledge of the character of this effect is essential in the designing of combustion chambers.

The present article deals with an investigation of the effect of basic parameters on the working process of a combustion chamber in the design stage. The investigation relates to the specific structural diagram of a combustion chamber (Figure 1) which is used extensively in stationary and transportation gas turbine plants.

The basic parameters which influence the working process in a combustion chamber are:  $a_p$ ,  $t_v$ ,  $t_g$ ,  $t_{pt}$ , and  $q_k$  ( $q_k$  is the heat stress of the combustion chamber in Cal/cm<sup>2</sup>/hr.) [For explanation of parameters referred, see table at end]. In the investigation the values assigned to the basic parameters were varied singly, i.e., all but one remaining numerically constant.

The influence of  $a_p$  was investigated with  $a_p$  varying between 3.0 and 1.5. Since all other basic parameters and particularly  $G_v$ ,  $t_v$ ,  $t_g$ ,  $\eta_k$ , ( $\eta_k$  being the efficiency factor of the combustion chamber) remain constant, both fuel consumption and the total coefficient of excess air are also constant. With fuel consumption constant and with the same heat stress, the dimensions of the flame tube also remain unchanged at all values.

The variation of  $a_{pt}$  indicates redistribution of the air entering the combustion chamber in the primary and cooling currents. The quantity of this redistribution with  $a_p$  varying between 3.0 and 1.5 is shown in the following table (with  $a_0$  at approximately 6.2).

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<u>Value of Coefficient of Primary Air</u>	<u>Fraction of Total Quantity of Air Entering in Primary Current</u>	<u>Fraction of Total Quantity of Air Entering in Cooling Current</u>
3.0	0.50	0.50
2.5	0.40	0.20 [sic]
2.0	0.30	0.70
1.5	0.25	0.75

As  $a_p$  decreases the average temperature of the flame rises considerably due to the fact that the heat generated by the fuel, remaining constant, becomes suited to the reduced quantity of primary air. As  $a_p$  decreases from 3.0 to 1.5 this temperature rises nearly 1.5 times, as shown by curve 1 in Figure 2.

Although the diameter of the flame tube and the expenditure of fuel maintain their respective values, as a result of the reduction in the quantity of gases when operating with a lower  $a_p$ , the ~~speed~~ of the products of combustion in the flame tube is decreased. But since the rise in the temperature  $t_f$  accompanies the decrease in  $a_p$ , the decrease in ~~speed~~ does not proceed in direct proportion with the reduction of  $a_p$ . For example, when  $a_p$  is reduced 2 times, the ~~speed~~ is lowered 1.5 times.

In connection with the rising flame temperature there occurs an increase in the amount of heat transferred from the flame to the walls of the flame tube. In the transition of  $a_p$  from 3.0 to 1.5, the amount of heat thus transferred increases nearly five times (with the walls of the flame tube at constant temperature). The percentage of heat absorbed by the walls of the flame tube from the heat of the fuel at  $a_p = 3.0$  is approximately 2, while at  $a_p = 1.5$ , the percentage increases to approximately 9.5.

Although the amount of cooled air increases with a lowering  $a_p$ , the heating of this air increases rapidly due to the greater increase in the amount of heat transferred from the walls of the flame tube. If at  $a_p = 3$  the heating temperature of the cooling air increases over its initial value ( $t_v = 300^\circ\text{C}$ ) by only  $10^\circ\text{C}$ , at  $a_p = 1.5$  the temperature rise will amount to  $60^\circ\text{C}$ .

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The walls of the flame tube, absorbing heat from the flame, pass it on by convection to the cooling air, and by radiation to the walls of the housing. From the walls of the housing, radiation heat is drawn off by the cooling air by convection.

The investigation conducted permitted <sup>observing the</sup> following variations in the quantities of convection and radiation heat from the walls of the flame tube, with varying  $a_p$ , under conditions of a continuously constant flame-tube wall temperature.

As  $a_p$  decreases, the amount of heat taken by convection by the cooling air from the flame tube decreases rather sharply while radiation heat varies very little. With  $a_p$  varying from 3.0 to 1.5, the amount of convection heat increases 8.5 times.

Such an increase in this heat brings about an even sharper rise in the <sup>velocity</sup> ~~speed~~ of the cooling air in the <sup>annular</sup> ~~air~~ space between flame tube and jacket, which (rise) is necessary to carry off the increased amount of convection heat from the walls of the flame tube heat.

The character of the increase in <sup>velocity</sup> ~~speed~~ of cooling air ( $C_{ov}$ ) with the lowering  $a_p$  is as follows. With  $a_p$  decreasing within the prescribed limits, and with constant flame tube temperature  $C_{ov}$  is increased 8 times. Accordingly, the hydraulic resistance in the <sup>annular</sup> ~~air~~ space between housing and flame tube increases 64 times and the combustion chamber, as a whole, will show a much great <sup>or</sup> ~~loss~~ in pressure.

It must therefore be concluded that the combustion chamber will have to operate with high coefficients of excess primary air since, under that condition, the lower average temperature of the flame and the lesser quantity of heat transferred to the flame tube permit lower cooling air rates and, consequently, lower pressure losses during combustion chamber operation.

As  $a_p$  decreases, the increasing <sup>velocity</sup> ~~speed~~ of cooling air brings about a more intensive take-off of the heat from the jacket walls, in connection with which the temperature of these walls will be lower, the less the value of  $a_p$  is suited to the combustion chamber's operation at the time.

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The variation in jacket wall temperature with varying coefficient of excess primary air is such that with  $a_p$  increasing within the prescribed limits, the temperature rises from 380°C to 540°C (with initial cooling air temperature at 300°C).

Consequently, calculation of the combustion chamber for operation at large  $a_p$  with the advantage of a lesser pressure loss, imposes somewhat on the temperature condition. Governing the service life of the housing metal, which must also be studied when choosing the metal for that part of the combustion chamber.

The reduction in the temperature of the jacket with  $a_p$  decreasing increases the temperature drop between the flame tube and the housing, which must serve to explain the slight increase in the amount of heat transferred by radiation from the flame tube to the jacket.

Increase in cooling air rate with lowering  $a_p$  brings about a considerable decrease in the diameter of the combustion chamber jacket, whereupon the width of the ~~ring~~<sup>annular</sup> space between jacket and flame tube decreases since flame tube diameter remains constant. With  $a_p$  decreasing within the prescribed limits the width of this space decreases almost 6 times (under conditions of this investigation from 120mm to 20mm).

The influence of  $t_v$  was examined with  $t_v$  varying from 200°C to 500°C.

An increase in this temperature decreases the heat required in reaching the same gas temperature, causing at the same time a rather sharp drop in fuel consumption. With  $t_v$  rising from 200°C to 500°C, fuel consumption is cut by more than two times.

As a result of such a sharp drop in fuel consumption, the air/fuel ratio and, accordingly, the total coefficient of excess air increase, the latter varying from 5 (at  $t_v = 200^\circ\text{C}$ ) to 12 (at  $t_v = 500^\circ\text{C}$ ).

Variation in initial air temperature with  $d_p$  constant brings about, in connection with the change in fuel consumption, a redistribution of air in the primary and cooling (air) flows. As the air temperature increases the flow of primary air is reduced and the flow of cooling air increases.

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Since the quantity of heat carried by the air into the fire space increases as the initial air temperature rises, with a constant coefficient of  $a_p$ , the average temperature of the flame also rises. The flame temperature rises 1.14 times as  $t_v$  changes from 200°C to 500°C. The variation in average flame temperature is influenced to a considerably greater extent by the coefficient of excess primary air than by the initial air temperature. Since lower fuel consumption, all other conditions being equal, is related to a higher initial air temperature, in connection with the lower fuel consumption the requisite dimensions for the fire space (i.e., its volume  $V_{op}$ , the diameter and length of the flame tube) will be ~~less~~ <sup>smaller</sup>, resulting in a reduction in the size of the combustion chamber.

The dimensions of the fundamental parts of the combustion chamber are reduced as the initial air temperature is increased from 200°C. With the air temperature at 500°C, the volume of the fire space constitutes only 40%, the diameter of the combustion chamber jacket about 60 percent, and the diameter and length of the flame tube about 75 percent of those dimensions which these parts of the combustion chamber normally possess at an air temperature of 200°C.

The ~~speed~~ <sup>velocity</sup> of the products of combustion in the flame tube varies in direct proportion to changes in the quantity of fuel being burned, and in inverse proportion to changes in flame-tube cross section. Since, with variation of  $t_v$ , the quantity of fuel being burned and the diameter of the flame tube vary in like directions (~~both~~ <sup>both</sup> quantities decrease as  $t_v$  decreases), it is apparent that the variation of  $t_v$  has almost no effect on the value of the ~~speed~~ <sup>velocity</sup> of the products of combustion,  $C_{pg}$ , which remains practically constant at all values of  $t_v$ .

The quantity of heat absorbed from the flame by the flame tube remains practically unchanged at all air temperature values, for although the average flame temperature increases as  $t_v$  increases, the surface of the flame tube is at the same time reduced.

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Since fuel consumption is sharply reduced when the air temperature is raised, ~~when~~ the quantity of heat absorbed by the flame tube, ~~is con-~~ sidered relative to the heat of the fuel used, ~~it~~ appears to increase considerably. For example, in the transition from an initial air temperature of  $200^{\circ}\text{C}$  to  $t_v = 500^{\circ}\text{C}$ , the percentage of fuel heat transferred from the flame to the surface of the flame tube increases from 3 percent to 7 percent.

A higher temperature of the jacket walls is in accord with a higher temperature of the air as it enters the combustion chamber.

The higher the temperature of the jacket, the lower (with flame-tube temperature constant) will be the amount of radiation heat from the flame tube to the walls of the jacket; and, accordingly, the greater will be the amount of convection heat from flame tube to cooling air. Since, however, with an increase in initial air temperature, fuel consumption is reduced simultaneously with the radiation heat from the flame tube, the quantity of radiation heat from the flame tube relative to the heat of the expended fuel appears to remain almost constant over the entire range of initial air temperatures ( $200^{\circ}\text{C}$  to  $500^{\circ}\text{C}$ ), constituting about 1 percent of the heat of the fuel being expended -- this as a result of the accumulating numerical relationships between the initial air temperature, fuel consumption and flame tube radiation heat.

As a result of the above-mentioned constancy the amount of convection heat given off by the flame tube to the cooling air, likewise relative to the heat of the fuel, varies under the different initial air temperatures similarly to the variation of the total quantity of heat absorbed by the flame tube.

The value for heating of the cooling air with respect to changes in its initial temperature varies very little (within the range of  $30^{\circ}\text{C}$  to  $20^{\circ}\text{C}$ ), decreasing as the initial temperature rises. Such a change is explained by the fact that the flow of heat going through the flame tube to the cooling air and remaining almost constant at all values of  $t_v$  is entirely

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insignificant with respect to the quantity of cooling air passing through, which quantity, moreover increases as the initial temperature rises.

It is then obvious that an increase in initial air temperature is always accompanied by the following: a decrease in temperature difference between flame tube and cooling air (with flame tube temperature constant); the heat output surface of the flame tube is reduced since, by reducing fuel consumption (with constant heat stress), the requisite dimensions of the flame tube are reduced; the amount of heat passed by the flame tube to the cooling air by way of convection is somewhat increased.

All this makes it necessary to intensify convection heat output from the flame tube to the cooling air which end is attained by increasing considerably the ~~speed~~<sup>velocity</sup> of cooling air in the ~~ring~~<sup>annular</sup> space between flame tube and jacket. Examination of the increase in the ~~speed~~<sup>velocity</sup> of cooling air along with a rise in initial air temperature reveals that the transition of initial air temperature from 200°C to 500°C involves the necessity of increasing the ~~speed~~<sup>velocity</sup> of cooling air almost 8 times in order to hold the temperature of the flame tube walls at a constant value. It may thus be concluded that with high initial temperatures  $t_v$ , operation of the combustion chamber will proceed with considerable pressure losses, due to the necessity of maintaining high cooling-air ~~speed~~<sup>velocity</sup> rates. In order to avoid any considerable losses in pressure it will obviously be necessary, at high  $t_v$ , to operate with the highest possible flame-tube temperatures.

The influence of  $t_g$  was investigated with  $t_g$  varying from 600°C to 900°C.

The higher the temperature of the gases, the greater will be the consumption of fuel. As a result of greater fuel consumption the total coefficient of excess air  $a_0$  will decrease, the amount of primary <sup>air</sup> will increase, and the amount of cooling air will decrease.

As  $t_g$  varies from 600°C to 900°C fuel consumption increases somewhat more than two times and the total coefficient of excess air decreases by the same amount.

In connection with the increasing fuel consumption, as  $t_g$  rises, the necessary volume of fire space increases. Accordingly, there is also an increase in the diameter, length and heat-absorbing surface of the flame

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All this makes it necessary to intensify convection heat output from the flame tube to the cooling air which end is attained by increasing considerably the ~~speed~~<sup>velocity</sup> of cooling air in the ~~ring~~<sup>annular</sup> space between flame tube and jacket. Examination of the increase in the ~~speed~~<sup>velocity</sup> of cooling air along with a rise in initial air temperature reveals that the transition of initial air temperature from 200°C to 500°C involves the necessity of increasing the ~~speed~~<sup>velocity</sup> of cooling air almost 8 times in order to hold the temperature of the flame tube walls at a constant value. It may thus be concluded that with high initial temperatures  $t_v$ , operation of the combustion chamber will proceed with considerable pressure losses, due to the necessity of maintaining high cooling-air ~~speed~~<sup>velocity</sup> rates. In order to avoid any considerable losses in pressure it will obviously be necessary, at high  $t_v$ , to operate with the highest possible flame-tube temperatures.

The influence of  $t_g$  was investigated with  $t_g$  varying from 600°C to 900°C.

The higher the temperature of the gases, the greater will be the consumption of fuel. As a result of greater fuel consumption the total coefficient of excess air  $a_0$  will decrease, the amount of primary<sup>air</sup> will increase, and the amount of cooling air will decrease.

As  $t_g$  varies from 600°C to 900°C fuel consumption increases somewhat more than two times and the total coefficient of excess air decreases by the same amount.

In connection with the increasing fuel consumption, as  $t_g$  rises, the necessary volume of fire space increases. Accordingly, there is also an increase in the diameter, length and heat-absorbing surface of the flame

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tube. As  $t_g$  changes from  $600^{\circ}\text{C}$  to  $900^{\circ}\text{C}$ , the surface of the flame tube increases 1.6 times.

Since, in the given case, the coefficient of excess primary air is a constant quantity, the average flame temperature  $t_f$  also remains substantially the same at all values of  $t_g$ . As the gas temperature rises the flame-tube surface increases resulting in the absorption of a larger quantity of heat from the flame by the flame tube. As  $t_g$  varies from  $600^{\circ}\text{C}$  to  $900^{\circ}\text{C}$  this quantity increases 1.7 times. The heat quantities  $Q_{rpt}$  and  $Q_{kpt}$  are increased by the same quantity.

However, since the quantity of fuel being consumed, as gas temperature rises, increases more rapidly than the quantity of heat absorbed from the flame by the flame tube, this heat quantity, expressed in percent of the heat from the fuel, is reduced as  $t_g$  increases. The heat absorbed by the flame tube lies within the limits of 4 percent to 3.5 percent of fuel heat. Since the temperature of the combustion-chamber jacket remains practically the same at all values of  $t_g$ , under the conditions of a constant flame-tube temperature, the amount of heat transferred by radiation from the flame tube to the jacket expressed in percent of fuel heat, remains unchanged, equal in this case to about 1 percent. As a result of this constancy, the amount of convection heat directly given off by the flame tube to the cooling air varies, and the variation, expressed in percent of fuel heat is entirely similar to the heat variation  $Q_{pt}$ . The variation in gas temperature  $t_g$  affects the value of the cooling air's final temperature. During an increase in gas temperature in connection with a considerable decrease in the amount of cooling air, and a simultaneous rise in the amount of heat transferred from the flame through the flame tube to the cooling air, the cooling-air temperature increases. If at  $t_g = 600^{\circ}\text{C}$ , the final temperature of the cooling air exceeds its initial temperature at the entrance to the combustion chamber by  $15^{\circ}\text{C}$ , at  $t_g = 900^{\circ}\text{C}$  the final cooling air temperature will exceed the initial temperature by  $55^{\circ}\text{C}$ .

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Variation of the gas temperature has practically no effect on the <sup>velocity</sup> ~~speed~~ of the cooling air in the <sup>annular</sup> ~~ring~~ space between flame tube and jacket, or on the jacket's temperature. Both quantities remain practically constant at all values of  $t_g$ .

A change in the temperature  $t_g$  shows an effect on the speed of the products of combustion in the flame tube. Since, as  $t_g$  rises, fuel consumption increases <sup>more rapidly</sup> ~~greater~~, proportionally, than does the cross-sectional area of the flame tube, the <sup>velocity</sup> ~~speed~~ of the products of combustion  $C_{pg}$  also shows an increase.

The effect of  $t_{pt}$  was investigated with  $t_{pt}$  varying from 600°C to 1000°C. With constant conditions of air consumption, initial air temperature, and gas temperature, a change in the temperature of the flame tube has no effect on fuel consumption, total coefficient of excess air, or air distribution <sup>in</sup> ~~the~~ primary and cooling flows, which remain the same at all values of  $t_{pt}$ .

With fuel consumption unchanged the requisite fire space and, consequently, the flame tube dimensions also remain unchanged. A change in the temperature of the flame tube affects the amount of heat absorbed by the flame tube from the flame. As the flame-tube temperature rises, due to the lessening difference in temperature between flame and tube the amount of heat transferred is reduced.

Examination of this reduction shows that the amount of heat  $Q_{pt}$  expressed in percent of the heat from the fuel consumed and averaging 4.5 to 3 percent, drops about 1.5 times as  $t_{pt}$  varies from 600°C to 1000°C.

The amount of heating of the cooling air in the ring space between flame tube and jacket varies in the <sup>m</sup> ~~same~~ relationship. If, with flame tube temperature at 600°C the final temperature of the cooling air,  $t_{ov}$ , exceeds by 30°C its initial temperature ( $t_v = 300°C$ ), at a flame tube temperature of 1000°C, the rise above initial air temperature is reduced to 20°C.

In the total quantity of heat brought into the fire space with the fuel and air, the heat absorbed by the flame tube hasn't a value sufficiently outstanding to permit judgment of the percentage quantity of this heat. For

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this reason variation in the heat absorbed by the flame tube does not show an effect on the average flame temperature, which remains practically invariant.

In addition, the temperature  $t_{pt}$  shows no effect on the ~~speed~~<sup>velocity</sup> of the products of combustion in  $C_{pg}$  in the flame tube, which ~~(speed)~~ remains practically constant at all values of  $t_{pt}$ . The reason for this constancy is that the values for fuel consumption and flame-tube diameter do not change.

A rise in flame-tube temperature, increasing the flame tube's radiation properties, causes an increase in the amount of heat transferred by radiation from the flame tube to the combustion chamber jacket. As the flame-tube temperature rises from 600°C to 1000°C, the amount of heat  $Q_{rpt}$  increases approximately 4 times.

As a result of such a great increase in the amount of heat transferred to the jacket, the jacket's temperature undergoes a considerable increase. This temperature varies from 340°C to 700°C. Consequently, combustion chamber operation at high flame-tube temperatures means high jacket temperatures also.

A lowering of the heat quantity  $Q_{pt}$  with an increase in the temperature  $t_{pt}$  and a simultaneous increase of  $Q_{rpt}$  brings about a significant reduction in the amount of heat given off by the flame tube directly to the cooling air by convection. As flame-tube temperature rises from 600°C to 1000°C, the amount of convection heat  $Q_{kpt}$  is reduced approximately 3 times.

So great a reduction in the convection-heat quantity  $Q_{kpt}$ , with a simultaneous widening of the temperature interval between flame tube and cooling air, conditions a sharp reduction in the ~~ring~~<sup>annular</sup> space between flame-tube and jacket. As flame-tube temperature changes from 600°C to 1000°C, this rate is reduced 4.5 times.

In connection with such a sharp cooling-air rate reduction, with cooling-air volume remaining almost constant at all values of  $t_{pt}$ , there appears the necessity for a larger ~~ring~~<sup>annular</sup>-space cross section resulting in an enlarged jacket diameter. As  $t_{pt}$  varies from 600°C to 1000°C, the enlargement factor is approximately 1.4.

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The influence of  $q_k$  was investigated with  $q_k$  varying from  $10 \cdot 10^6$  Cal/cu m/hr to  $50 \cdot 10^6$  Cal/cu m/hr.

A change in the dimensions of the combustion chamber is directly related to a change in the heat-stress quantity. As heat stress increases there is a directly proportioned decrease in the requisite fire-space volume, and consequently a reduction in the length and diameter of the flame tube, diameter of the jacket and surface of the flame tube and jacket, which are part of the heat-exchange pattern. A five-fold increase in heat stress involves an approximate 45 percent reduction in flame tube diameter and a 65 percent reduction in flame-tube surface.

At all heat-stress values, the total coefficient of excess air, air distribution in primary and cooling air flows, and fuel consumption remain the same when the air and gas parameters  $G_v$ ,  $t_v$ ,  $t_g$ ,  $a_p$  are invariant.

With an increase in heat stress as a result of a reduction in flame-tube surface, and with fuel consumption constant, the amount of heat transferred from flame to flame tube decreases.

In the transition of  $q_k$  from  $10 \cdot 10^6$  to  $50 \cdot 10^6$  Cal/cu m/hr, the amount of heat absorbed by the flame tube from the flame is reduced approximately 2.5 times. Although this reduction is in itself significant, since the amount of heat given off from flame to flame tube, by comparison with fuel heat, is quite small (in the given case, it varies from 7 percent to 2.6 percent), the average temperature of the flame remains practically the same at all heat-stress values. With a five-fold increase the flame temperature rises about  $50^\circ\text{C}$ .

A sharper drop in heat  $Q_{pt}$ , with  $q_k$  increasing, <sup>shows up</sup> ~~appears~~ in the degree of heating of the cooling air in the <sup>annular</sup> ~~ring~~ space between flame tube and jacket.

In accordance with the decrease in  $Q_{pt}$ , with  $q_k$  increasing, the amount of heat transferred by radiation from flame tube to jacket,  $Q_{rpt}$ , and the amount of heat transferred by convection from the flame tube directly to the cooling air,  $Q_{kpt}$ , decreases.

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A decrease in  $Q_{rpt}$  is the cause of a small but discernible reduction in jacket temperature as heat stress increases. If, at  $q_k = 10 \cdot 10^6$  Cal/cu m/hr the jacket temperature exceeds initial air temperature by  $165^\circ\text{C}$ , at  $q_k = 50 \cdot 10^6$  Cal/cu m/hr, the difference will be approximately  $125^\circ\text{C}$ .

A change in heat stress has practically no effect on the variation in average cooling-air ~~speed~~<sup>velocity</sup> in the ~~ring~~<sup>annular</sup> space between flame tube and jacket, which (~~speed~~<sup>velocity</sup>) increases very little as heat stress rises. The five-fold increase in heat stress causes no more than a 20 percent rise in cooling-air ~~speed~~<sup>velocity</sup>. This small variation of  $C_{ov}$  at various values of  $q_k$  is explained by the opposite and, at the same time, practically uniform effects of the convection heat flow from one square meter of flame-tube surface, and the temperature difference between flame tube and cooling air.

A reduction of flame-tube diameter with an increase in heat stress is the cause of a considerable increase of the ~~speed~~<sup>velocity</sup> of the combustion products in the flame tube. With a five-fold increase in heat stress, this ~~speed~~<sup>velocity</sup> increases almost 3 times.

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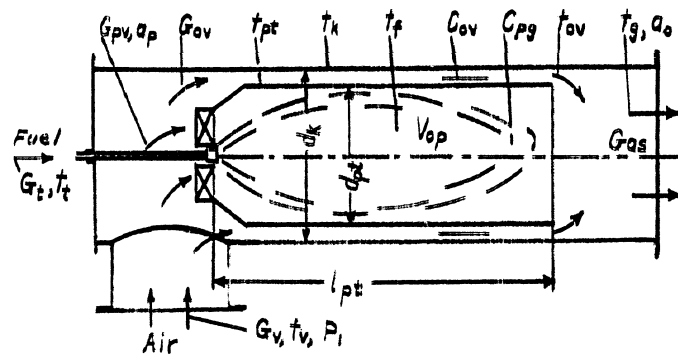
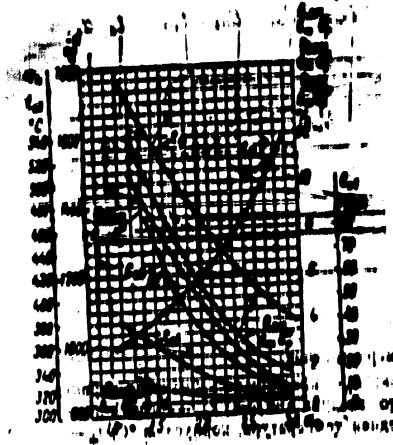


Figure 1- Diagram of Combustion Chamber

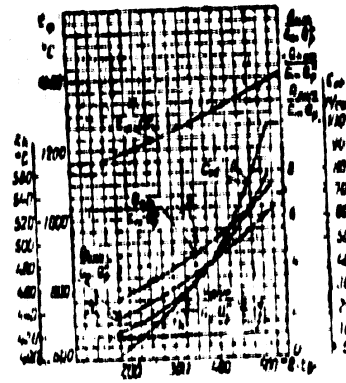
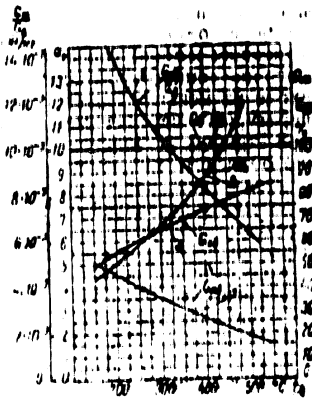
[Figures 2-11 are given in the original document available in FDD Library.]

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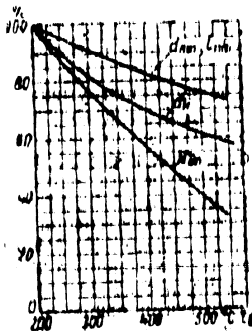
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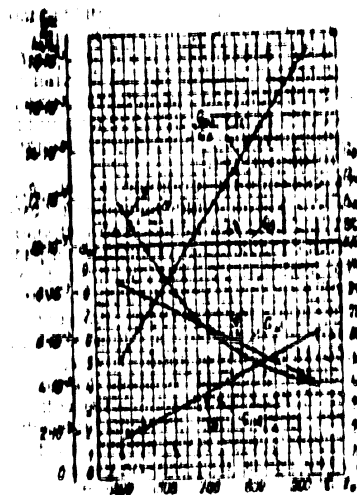
*Graph showing the influence of inlet temperature on the rate of reaction.*



*Graph showing the influence of inlet temperature on the rate of reaction.*



*Graph showing the influence of inlet temperature on the rate of reaction.*



*Graph showing the influence of inlet temperature on the rate of reaction.*

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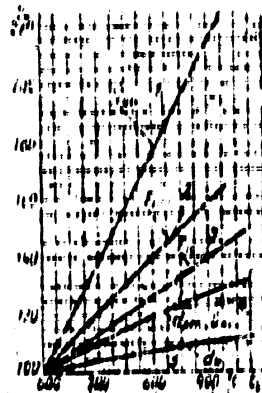


Figure 7. Influence of the temperature of bases

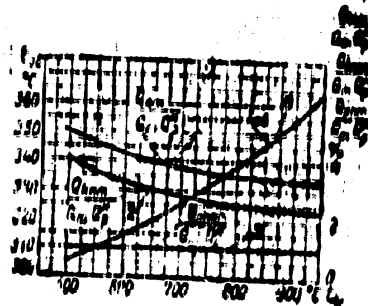


Figure 8. Influence of the temperature of bases

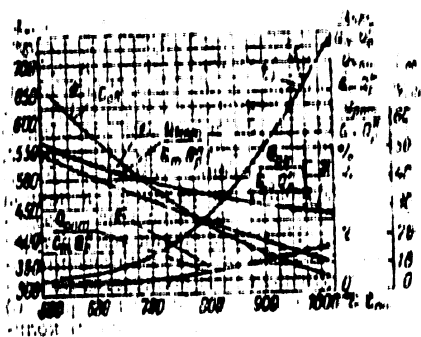


Figure 9. Influence of the temperature of flame tube

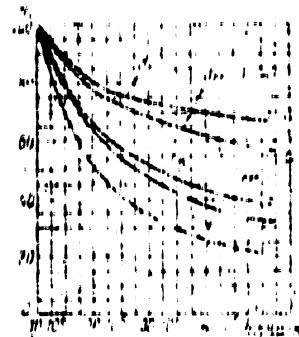


Figure 10. Influence of the thermal stresses

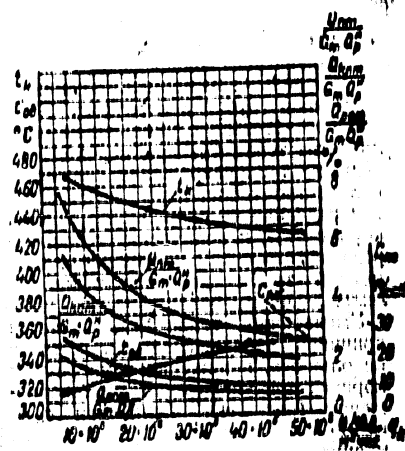


Figure 11. Influence of the thermal stresses

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## Table of Parameters

$G_{pv}$  - consumption of primary air in kg/sec  
 $a_p$  - coefficient of excess primary air  
 $G_{ov}$  - consumption of cooling air in kg/sec  
 $t_{pt}$  - average flame-tube temperature in  $^{\circ}\text{C}$   
 $t_k$  - average jacket temperature in  $^{\circ}\text{C}$   
 $t_f$  - average flame temperature in  $^{\circ}\text{C}$   
 $G_{ov}$  - average ~~speed~~<sup>velocity</sup> of cooling air in ring space between flame tube and jacket in m/sec  
 $C_{pg}$  - ~~speed~~<sup>velocity</sup> of the products of combustion in the flame tube at  $t_f$  in m/sec  
 $t_{ov}$  - temperature of the cooling air at the end of the ring space between flame tube and jacket in  $^{\circ}\text{C}$   
 $t_g$  - temperature of exit gases from combustion chamber in  $^{\circ}\text{C}$   
 $a_o$  - total coefficient of excess air  
 $G_v$  - total air consumption through combustion chamber in kg/sec  
 $t_v$  - temperature of air at entrance to combustion chamber in  $^{\circ}\text{C}$   
 $P_1$  - pressure of air at entrance to combustion chamber in atms  
 $G_t$  - fuel consumption in kg/hr  
 $d_k$  - diameter of jacket  
 $d_{pt}$  - diameter of flame tube  
 $l_{pt}$  - length of flame tube  
 $V_{op}$  - volume of fire space  
 $Q_{kpt}$  - heat (convection) given off by flame tube  
 $Q_{rpt}$  - heat (radiation) given off by flame tube  
 $Q_{pt}$  - heat absorbed by flame tube from flame

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